Book Title
Book Editors
IOS Press, 2003

Simulated Artificial Human Vision: The Effects of Spatial Resolution and Frame Rate on Mobility

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Abstract. Electrical stimulation of the human visual system can result in the perception of blobs of light, known as phosphenes. Artificial Human Vision (AHV or visual prosthesis) systems use this method to provide a visual substitute for the blind. This paper reports on our experiments involving normally sighted participants using a portable AHV simulation. A Virtual Reality Head Mounted Display is used to display the phosphene simulation. Custom software converts captured images from a head mounted USB camera to a DirectX based phosphene simulation. The effects of frame rate (1, 2 and 4 FPS) and phosphene spatial resolution (16x12 and 32x24) on participant Percentage of Preferred Walking Speed (PPWS) and mobility errors were assessed during repeated trials on an artificial indoor mobility course. Results indicate that spatial resolution is a significant factor in reducing contact with obstacles and following a path without veering, however the phosphene display frame rate is a better predictor of a person's preferred walking speed. These findings support the development of an adaptive display which could provide a faster display with reduced spatial resolution when a person is walking comfortably and a slower display with higher resolution when a person has stopped moving.

Keywords. visual prosthesis, blind mobility, artificial human vision, image processing,

1. Introduction

1.1. Blind mobility

An important usability requirement for an Artificial Human Vision (AHV) system is the ability to move safely and confidently. One widely used mobility measure for the blind and visually impaired is the Percentage of Preferred Walking Speed (PPWS) and a count of mobility incidents (generally defined as contact with obstacles) (for example, [6] and [7]). PPWS requires a measure of a person's Preferred Walking Speed (PWS), which is generally obtained by an instructor guiding a participant over a known distance and dividing the distance by the time taken. Walking efficiency can then be calculated

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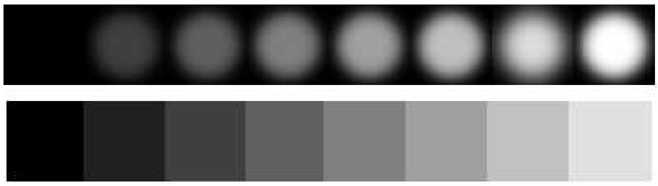

Figure 1. Phosphenes displayed for grey level pixels in reduced resolution images

as a percentage of the PWS [7]: $PPWS = SMC/PWS \times 100$, where $SMC = distance/time$. The PPWS can be used as a between participants measure to compare different walking speeds, in addition to assessing mobility changes in a single participant.

1.2. Artificial Human Vision (AHV)

AHV involves the delivery of electrical impulses to a component of the visual pathway where they may be perceived as phosphenes, or points of light. Currently four locations for stimulation are being investigated: behind the retina (subretinal), in front of the retina (epiretinal), the optic nerve and the visual cortex (using intra and surface electrodes) [3]. A typical AHV system involves a head-mounted camera; image processing unit; a transmitter/receiver; stimulator unit and an electrode array. The number of perceived phosphenes is constrained by the number of electrodes, therefore image processing techniques are required to reduce the spatial resolution of captured images. There are also limits to the rate at which phosphenes can be presented. For example, the only commercially available cortical device is limited to one frame per second (FPS) (Dobelle (2000)).

Due to the difficulty in obtaining experimental participants with an implanted AHV device, a number of simulation studies have been conducted with normally sighted subjects, for example: [1], [2], [4], [5] and [8]. However, there is little published research on the effects of image processing on AHV mobility performance. A focus of current AHV research is to increase the number of implantable electrodes and therefore increasing perceived spatial resolution, however the effect of frame rate on mobility for an AHV display has not been explored. The current study investigates the effect of display frame rate (1,2 and 4 FPS) and spatial resolution (32x24 and 16x12 phosphenes) on the frequency of mobility errors and PPWS measured on an indoor artificial mobility course.

2. Method

2.1. Simulation Hardware

An i-O Display Systems i-glasses PC/SVGA Head Mounted Display (HMD) was used in this study, powered from an external lithium polymer battery. The HMD screen distance was 25 mm from the wearer's eyes. A Swann Netmate USB camera was attached, at eye level, to the front of the HMD. This camera was powered from the USB port of a Toshiba Tecra laptop (1.6GHz Centrino processor). To block out external light, a custom shroud was made from block out curtain and attached to the HMD.

2.2. Simulation Software

The main requirement for our AHV simulation software was to convert input from the camera into an on-screen phosphene display. Our simulation reduces the resolution of captured images from 160x120 RGB colour to 32x24 or 16x12 eight grey-level simulated phosphenes. Our simulation, written in Microsoft Visual C++ 6.0, uses the Microsoft Video for Windows library to capture incoming video images. These images are sub-sampled (using the mean grey level of contributing pixels) to a lower resolution image, which is then converted to 8 grey levels. To simulate a perceived electrode response the low resolution image is displayed as a phosphene array using the DirectDraw component of Microsoft DirectX. Figure 1 shows the mapping between image grey levels and the different phosphene representations. Each phosphene was generated from an original 40 pixel wide circle, filled with the matching grey level, and blurred with a Gaussian filter (r=10). Examples of the simulation display are shown in Figures 2 to 4.

Figure 2. Original 160x120 pixel captured image

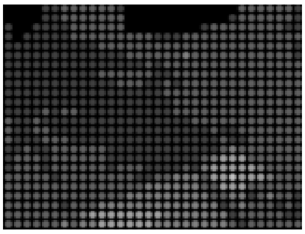

Figure 3. Original image reduced to 32x24 phosphenes

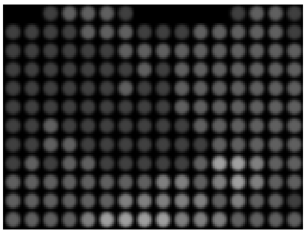

Figure 4. Original image reduced to 16x12 phosphenes

2.3. Mobility course

To assess mobility performance, an indoor mobility course (Figure 5) was constructed within a 30x40m laboratory at the School of Civil Engineering, Queensland University of Technology. The course consisted of a winding path, approximately 1m wide and 30m long. Path boundaries were marked with 48mm black duct tape. The floor of the course consisted of concrete (generally light grey with a $3m^2$ section painted white from a previous study). Grey office partitions were placed on either side of the path to reduce visual clutter and to prevent participants from confusing the neighboring path with the current path. Eight obstacles, painted in different shades of matt grey, were placed through the course (see Figure 6). Two of the obstacles were suspended from the ceiling to a height of 1.2 m. All obstacles along the path were made from empty packing boxes (450x410x300mm). A straight, unobstructed, 10m section of the course was used to measure the Preferred Walking Speed (PWS) of each participant.

2.4. Participants

Ten female and 50 male volunteers were recruited from staff and students at different faculties at the Queensland University of Technology. Four participants were aged between 0-20 years; 32 were aged between 20-30; 12 were between 30-40; 9 were between 40-50; 2 were between 50-60; and 1 participant was aged over 60 years. All participants had normal or corrected to normal vision.

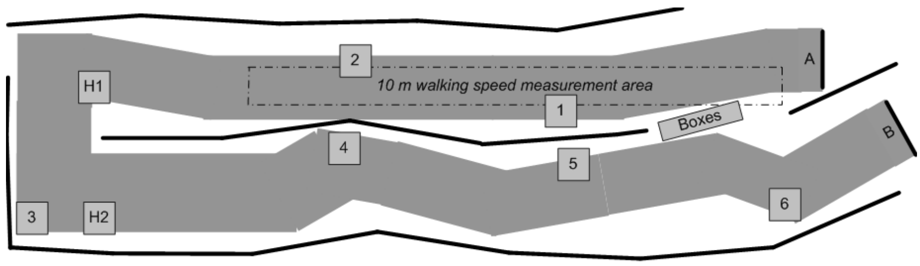

Figure 5. Map of the artificial mobility course built for this study

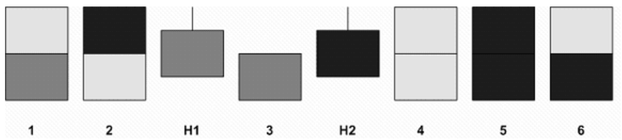

Figure 6. Different types of grey shading on each obstacle shown in Figure 5

2.5. Questionnaire

Details of gender, age and whether the participant was wearing glasses or contact lenses were collected from a questionaire. In addition, participants were asked how many times (if any) they had used an immersive Virtual Reality environment.

2.6. Procedure

Each participant was randomly allocated to a frame rate and display type level and commenced their first trial with one of the two course start locations (marked 'A' or 'B' in Figure 5). One hour was allocated for testing each individual. Study participants were met in a corridor outside the lab, asked to read a consent sheet and fill out the questionnaire. The simulation headgear was then explained and fitted before the participant was led into the concrete lab. Each participant was then allowed two minutes to familiarise themselves with the display. The guided PWS was then recorded over 10m. After this the participant was led to the trial starting location ('A' or 'B') and the first mobility trial was conducted. Participants were offered a short break before the second trial was conducted. Finally, the PWS was measured for the second time. During the mobility trials, a single experimenter recorded walking speed, obstacle contacts, the number of times participants were told they were walking backwards and the number of times participants veered outside the path boundary.

3. Results

A summary of the mobility results are provided in Table 1. No participants reported nausea during the experiment, although two required a break between trials.

The initial and final measurements of Preferred Walking Speed (PWS) were significantly correlated (r=0.67, p<.01), as was Speed on the Mobility Course during the two

Table 1. Mean scores (with standard deviations) for the main dependent variables. PPWSA refers to the the mean PPWS score from the first trial, PPWSB refers to trial 2. The obstacle contact and veering columns are the combined mean and standard deviation totals for trials 1 and 2.

Resolution	Frame Rate	PPWSA	PPWSB	Total Veering Incidents	Total Obstacle Contacts
16x12	1	21.24 (13.56)	19.96 (11.22)	8.00 (2.67)	23.00 (5.90)
	2	17.15 (8.92)	18.29 (10.58)	7.30 (2.26)	22.60 (7.11)
	4	22.16 (5.19)	23.52 (4.97)	7.70 (1.95)	19.60 (3.63)
32x24	1	18.12 (5.89)	22.52 (8.31)	6.80 (2.04)	17.80 (7.96)
	2	22.78 (9.06)	20.84 (5.59)	7.80 (2.44)	12.50 (6.11)
	4	25.24 (9.52)	29.65 (9.54)	5.90 (2.42)	11.80 (7.21)

mobility trials (r=0.87, p<.01). The relationship between PPWSA and PPWSB was also significant (r=0.80, p<.01). These results support the reliability of the PPWS measure.

A 2x3 analysis of variance (ANOVA) was performed to investigate the effect of frame rate (FPS) and resolution on PPWS on the first trial (PPWSA) and second trial (PPWSB). Significant findings were not found for the initial trial (PPWSA): this may be due to variability in participants becoming comfortable with the display.

The PPWS result from the second trial (PPWSB) was significantly affected by FPS (F(2,54)=3.56, p<.05)). Post-hoc Tukey's HSD analyses revealed significant differences between FPS values of 2 and 4 (p<.05). Overall veering was significantly less with a higher level of spatial resolution (F(1,54)=21.25, p<.01). There was also a marginal relationship found between increased frame rate and reduced overall veering (F(2,54)=13.342, p=.08).

There was no significant difference found between overall obstacle frequency and resolution (F(1,54)=0.08, p=.78). Female participants were found to have significantly fewer overall obstacle contacts than males (F(1,54)=9.27, p<.01). Twenty-two subjects had corrected-to-normal vision, although there were no significant differences between these subjects and those without correction.

4. Discussion

The highly significant relationships between pre- and post-trial Preferred Walking Speed support the use of the PPWS method as a mobility assessment measure for AHV research. Combined with veering and obstacle contacts, these dependent variables can form the basis for an objective method to assess the effects of different image processing methods in both simulated and real AHV systems. This method of assessment could also be extended to comparing different blind mobility aids (such as a long cane) with an implanted AHV system.

The results from this study indicate that spatial resolution is more useful than increased frame rate for reducing contact with obstacles and following a path without veering. However the display frame rate has a significant effect on a person's preferred walking speed. These findings support the development of an adaptive AHV system which could provide a lower resolution/faster display while a person is moving and a higher resolution/slower display when a person has stopped moving.

Interestingly, three participants reported useful echolation from nearby partitions as they were walking. One participant reported trying to use sound to assist with navigation.

Future work could investigate the effects of learning with different resolution and frame rate. Learning effects have previously been found by Cha et al (1992), although their simulation did not use image processing. As shown in Table 1, mean scores generally improved between the first and second trials. An extraneous variable could also be the level of confidence each participant felt while being effectively blindfolded in a strange environment during the study. Some participants also required time to adjust to the location of camera and the associated difference in display viewing angle from their usual vision. As these participants tended to be looking too high to locate the path boundaries, an artificial horizon indicator could be useful.

Acknowledgements

This research was supported by Cochlear Ltd. and the Australian Research Council through ARC Linkage Grant project 0234229.

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